N64 13274
CR - 53004

70

Reprinted without change of pagination from
Icarus, Vol. 2, pp. 49-53, June, 1963

Technical Report No. 32-462

High Dispersion Spectra of the Outer Planets. II. A New Upper Limit for the Water Vapor Content of the Martian Atmosphere

Hyron Spinrad
E. H. Richardson

CASE FILE COPY

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS 7-100, sponsored by the National Aeronautics and Space Administration.

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

June, 1963

ICARUS 2, 49–53 (1963)

High Dispersion Spectra of the Outer Planets. II. A New Upper Limit for the Water Vapor Content of the Martian Atmosphere[1]

HYRON SPINRAD AND E. H. RICHARDSON

Division of the Space Sciences, Jet Propulsion Laboratory, Pasadena, California

and

Dominion Astrophysical Observatory, Victoria, B. C., Canada

Communicated by A. G. Wilson

Received March 28, 1963

On a very high dispersion spectrogram of Mars we have searched unsuccessfully for Martian H_2O lines near λ 7200. The plate was taken on a very dry night when the Doppler shift was sufficient to displace any Mars H_2O lines 0.29 Å from their telluric counterparts. From this data we have derived an upper limit for the integrated Martian water vapor abundance of approximately 3.5×10^{-3} gm/cm^2 (35 μ). The practical limits for detection of Martian water vapor by Earth-bound, balloon, and space probe techniques indicate that spectroscopic observations from the Earth can be refined to a point where they are at least as sensitive as present infrared space experiments.

Introduction

The most recent of a long list of unsuccessful spectroscopic searches for Martian water vapor was made by Kiess *et al.* (1957). Their conservative estimate of the Martian H_2O abundance placed the upper limit at 8×10^{-3} gm/cm^2 (80 μ precipitable water). The more severe upper limit of approximately 10 μ determined by Dunham (1952) has been criticized by Hess (1961). Our new determination takes into account the actual meteorological conditions at Victoria during the observation, and uses a well-determined curve of growth for both the telluric and hypothetical Martian H_2O lines. However, we must note that the older H_2O upper limits and ours refer to a large ambiguous region on the daylight side of Mars. We did not have enough spacial resolution to observe a particular region of the planet—like a melting zone near a polar cap. To do this one would need the scale of the Hale reflector or the Lick 120-inch.

The Observation

E. H. Richardson obtained an excellent high dispersion spectrogram of Mars (V 477) on December 24, 1962 with the 96-inch coudé camera at the Victoria 48-inch reflector. The dispersion was 3.1 Å/mm on water-sensitized I—N emulsion. The 7 hour exposure covers the region λλ 6900–7900. Unfortunately no image rotator was available, so the planet rotated under the slit about 100° during the exposure. First examination of the spectrogram indicated that a very sensitive determination of the Martian H_2O abundance was possible since the telluric water vapor lines were much weaker than usual at Victoria. At this date the Doppler shift at λ 7200 was −0.29 Å.

[1] Contributions from Dominion Astrophysical Observatory, No. 82. Published by permission of the Deputy Minister, Department of Mines and Technical Surveys, Ottawa, Canada.

The Reduction Procedure

We have searched for weak Martian water vapor lines 0.29 Å shortward of their telluric counterparts in two ways. First, we made direct intensity microphotometer tracings at Victoria and at the California Institute of Technology at the λ 7200 H_2O band region. Examination of these tracings at unblended telluric H_2O lines and at H_2O lines blended only on their longward wings in the solar spectrum, indicated no line asymmetries (see Fig. 1). The Doppler shift of —0.29 Å would be sufficient to shift any Martian water vapor line almost clear of the corresponding telluric line; the Martian component would lie far out on the shortward wing of the telluric line. Figure 2 indicates schematically a hypothetical Mars H_2O line superposed on a typical strong telluric water vapor line on plate V 477. The line profile for the telluric line is taken directly from the tracings; the hypothetical Mars line has an equivalent width of 10 mÅ and a half-width equal to that of the instrumental contour, observed by tracing lines in the iron-arc comparison spectrum. Figure 2 shows a noticeable asymmetry not observed in the Mars spectrum. The second search method is probably even more sensitive; visual inspection of the plate under suitable magnification shows weak solar lines down to $W_\lambda = 8$ or 9 mÅ. No Martian H_2O lines of this strength can be seen near the telluric water vapor lines; the Doppler shift appears sufficient to clear the shortward wings of the Earth's water vapor lines in a visual inspection of the plate and on enlarged high-contrast prints of this spectrogram.

The reason for a superior detection limit for Martian H_2O lines compared to a similar attempt for Venus (Spinrad, 1962) is

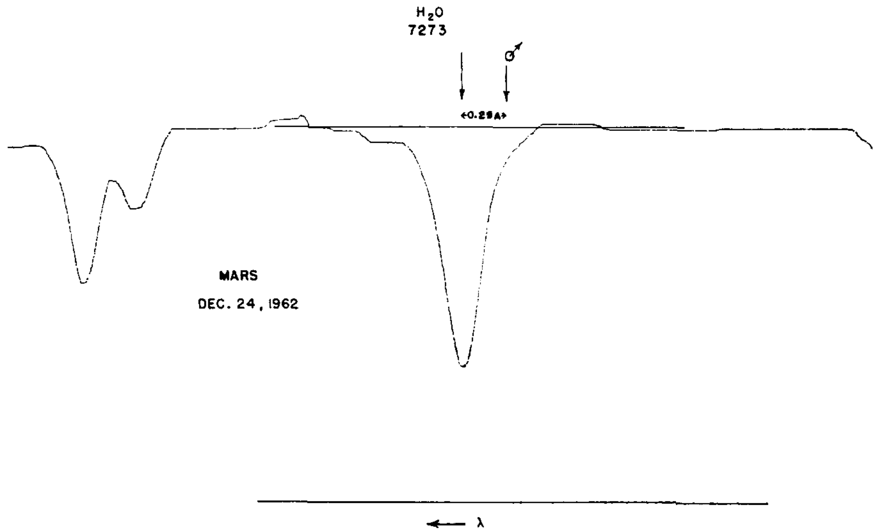

FIG. 1. The actual tracing of the region near λ 7273 on Victoria plate V 477. The position of the Martian H_2O line component is indicated by an arrow; there is *no* line asymmetry visible.

that any Martian planetary lines would be intrinsically very sharp. They are narrow due to the low pressures (~0.1 atm) and fairly low temperatures prevalent on Mars. The Lorentz and Doppler widths of any Martian water vapor lines in the photographic infrared would be considerably below the instrumental slit width; the total half-width of the comparison lines was 0.09 Å on V 477. Thus any Martian lines would have a profile like the Fe arc comparison lines—while for Venus, where pressures are high, planetary lines could be quite broad. The broad Cytherean lines would be much harder to detect by visual inspection or careful spectrophotometry than any sharp Martian features.

Since we state that there are no Martian

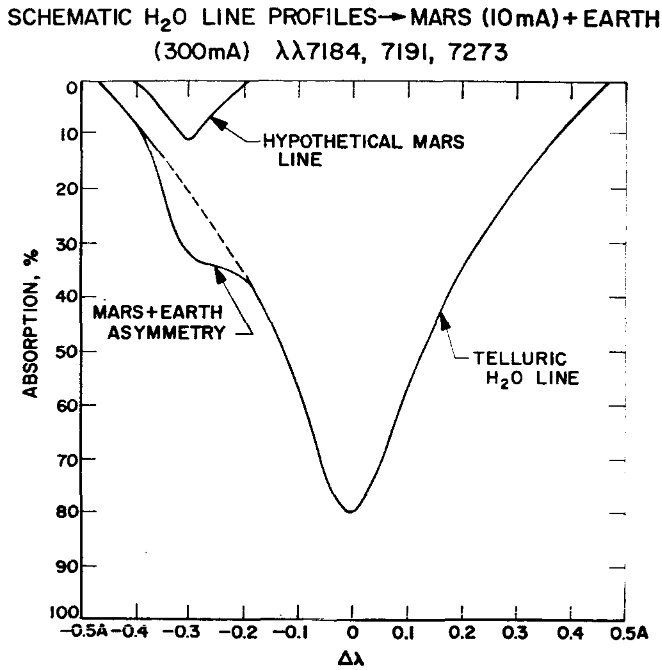

FIG. 2. The superposition of a *hypothetical* Martian H_2O line on a telluric H_2O line in the λ 7200 band. Note the asymmetry in the shortward wing of the composite line. Such asymmetry is not observed in the Mars near-infrared spectrum, however.

H_2O lines with strengths $W_\lambda > 9$ mÅ, we can deduce only an upper limit to the integrated H_2O content of the Mars atmosphere. First, we need to know some meteorological data on the conditions above Victoria on December 24, 1962. Through the cooperation of the Chief Forecaster at the Meteorological Office in Vancouver, B. C., and the U. S. Weather Bureau stations at Seattle and Olympia, Washington, we have determined the amount of precipitable H_2O above Victoria. We find that $\mathcal{W}_\oplus = 0.4$ gm/cm^2 (4 mm H_2O) in the vertical above the observatory at the time of the Mars exposure. The night was indeed quite dry. We estimate from the radiosonde data that the mean temperature in the Earth's water vapor layers ($\bar{P} \approx 0.8$ atm) was then about −15°C (258°K). This value is probably not much greater than the temperature of the lower atmosphere of Mars on the dayside (∼240°K)—so in our abundance limit to follow we have assumed any Boltzmann-type temperature correction to the Martian H_2O content to be negligible. For our strong lines, a temperature difference of some 20°K does not affect the line strengths more than 10–20%. The rotational lines which are strong in the Earth's atmosphere are, to a good approximation, the ones to look for on Mars.

We have measured the strengths of the strongest unblended telluric H_2O lines (λλ 7184, 7191, 7273); their W_λ ranges from 200–300 mÅ. That means they are about 30 times as strong as our detection limit. To convert the ratio of the strengths of the telluric H_2O lines and our hypothetical detection-limited Mars lines to a *relative* number of H_2O molecules we employ Goldberg's (1954) curve of growth. Table I lists some parameters for the Earth and Mars necessary for the curve-of-growth reduction. We find parameter $a = 4.45$ for the Earth and 0.28 for Mars; log $(W_\lambda/2b_D) = 1.15$ for Earth and −0.3 for Mars. Entering the curve of growth with these values we find the factor of 30 in line strengths gives an approximate factor of

TABLE I
PARAMETERS NECESSARY FOR H_2O CURVE-OF-GROWTH REDUCTION

Parameter	Earth	Mars
$\Delta\lambda_D$	19 mÅ	18 mÅ
b_D	9.5 mÅ = 0.018 cm^{-1}	9 mÅ = 0.017 cm^{-1}
Average pressure in H_2O region	0.8 atm	0.05 atm
γ_{H_2O}	0.08 cm^{-1}	0.005 cm^{-1}
$\gamma/b_D = a$	4.45	0.28
W_λ	270 mÅ	9 mÅ (detection limit)
$W_\lambda/2b_D$	14.2	0.50
$\log (W_\lambda/2B_D)$	1.15	−0.3

52 in the relative number of H_2O molecules due to the saturation of the strong telluric lines. The sharp Martian lines would be only slightly saturated. Their Doppler widths would be some 3–4 times their Lorentz widths. An independent curve-of-growth analysis by Dr. L. D. Kaplan agrees with our result. He used a technique developed by Kaplan and Eggers (1956). Since we observed Mars between quadrature and opposition the sunlight path was $(\sec i + \sec z) \simeq 3.3$ Martian air-masses for the oblique transversal in the Martian atmosphere. Fortunately Mars was high in the Victoria sky at the time of observation; $\sec z = 1.4$ for this plate. Thus the telluric H_2O lines on our spectrogram were formed by $(1.4) \times 0.4$ gm/cm² = 0.56 gm/cm² H_2O. We then find our upper limit to the Martian water vapor content (in microns) to be:

$$W_{♂} \leqslant \frac{5600}{(52)(3.3)}$$

which means $W_{♂} \leqslant 35\,\mu$ or $3.5 \times 10^{-}$ gm/cm². This low upper limit should be good to an estimated accuracy of about 30%. Our limit approaches the theoretical equilibrium lower limit of $10\,\mu$ set by Kellogg and Sagan (1961) under the assumption of a water-ice cap.

THE FUTURE

It is of interest to speculate on the likely sensitivities of future ground-based, balloon, and space-probe searches for water vapor on Mars.

Observations employing the Doppler shift technique are capable of pushing the detection limit well below our value of $35\,\mu$ precipitable water. We compute that high dispersion spectroscopic observations made on a cold, dry night, say with $W_\oplus = 2$ mm precipitable H_2O, could detect any Martian water-vapor abundance over $10\,\mu$ if the λ 8200 band is observed. With these stronger lines a larger curve-of-growth factor increases the sensitivity of the technique and the Doppler shifts reach ±0.41 Å at quadrature. If infrared image tubes extend the wavelength range of reasonable exposures at high dispersion to the λ 11,350 H_2O band one should be able to improve the Mars detection limit to about $4\,\mu$ under the best of observing conditions. If the Martian polar caps are water-ice we should find measurable Martian H_2O lines on such infrared spectra.

The balloon technique requires ascent to over 80,000 ft, which leaves a small, but apparently variable, amount of stratospheric water vapor above the observer. Sagan (1963) estimates that with a comparison standard such as the Moon, Stratoscope observation of the absolute amounts of H_2O at the 1.38 μ and 1.87 μ bands could detect some $10\,\mu$ of Martian H_2O if the observing conditions are stable. Presumably a fly-by probe alleviates the necessity of correction for any residual telluric water vapor but energy and resolution limitations indicate that for the present generation of Mars infrared spectrometers, some 15–10 μ precipitable H_2O is the limit of detection on Mars. However, the probe has the advantage of better spacial discrimination, and thus the location of Martian "Oases," if they exist, may be possible.

Note Added in Proof—May 23, 1963

As suggested in this paper, the detection of Martian H_2O lines at $\lambda 8200$ by the Doppler shift technique is quite possible. Several Mars water vapor lines were detected by Spinrad, Münch, and Kaplan from Mount Wilson on April 12/13, 1963. A preliminary abundance estimate suggests about 5–10 μ precipitable H_2O for Mars.

Acknowledgments

It is our pleasure to thank the staff of the Dominion Astrophysical Observatory for their cooperation. We also wish to thank Dr. L. D. Kaplan for helpful suggestions on the curve-of-growth reduction for water vapor.

References

Dunham, T. (1952). Spectrographic observations of the planets at Mount Wilson. *In* "The Atmospheres of the Earth and Planets" (G. P. Kuiper, ed.), pp. 296–301. Univ. of Chicago Press, Chicago, Illinois.

Goldberg, L. (1954). The absorption spectrum of the atmosphere. *In* "The Earth as a Planet" (G. P. Kuiper, ed.), pp. 434–490. Univ. of Chicago Press, Chicago, Illinois.

Hess, S. L. (1961). Mars as an astronomical objective. *Adv. Space Sci. and Technol.* **3**, 151–193.

Kaplan, L. D., and Eggers, D. F. (1956). Intensity and line-width of the 15-micron CO_2 band, determined by a curve-of-growth method. *J. Chem. Phys.* **25**, 876.

Kellogg, W. W., and Sagan, C. (1961). "The Atmospheres of Mars and Venus." Rept. of the Space Sci. Board, Natl. Acad. Sci.–Natl. Res. Council.

Kiess, C. C., Corliss, C. H., Kiess, H. K., and Corliss, E. L. R. (1957). High-dispersion spectra of Mars. *Astrophys. J.* **126**, 579.

Sagan, C. (1963). Private communication.

Spinrad, H. (1962). A search for water vapor and trace constituents in the Venus atmosphere. *Icarus* **1**, 266.